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THE CHANGING UNIVERSE

The three sections of this article on "The Changing Universe" were parts of a radio broadcast in the CBC series "Science Review". They were heard over the CBC network on July 23, 1957. We believe they will be of general interest to readers of this Journal—Editors.

Part I By John F. Heard

The idea of progressive change or of evolution (if you will accept that term in its broadest sense) is one of the most important concepts which have come from modern scientific research. We accept readily nowadays the hypothesis that plant and animal life have changed, that the earth's climate has changed and that the earth itself has changed. Scientists have not discovered these changes by direct observations of the changes taking place, but rather by study of the records left in fossil beds, in coal and oil deposits and in the rocks themselves. It has become clear that the changes have been extremely slow and that the records go back several billion years. The earth, it turns out, is at least four billion years old.

What about the stars and the materials composing them? Have they changed too? Until recently I think we have tended to resist such an idea. The stars—we have wanted to believe—are surely immutable and eternal; or almost so. But are they? The answer, as my colleagues will tell you presently, appears to be: the stars are indeed changing—and more rapidly and more radically than we used to think possible, though still so slowly that it is only in the records that we can read the story.

My purpose is mainly to explain to you the kind of information and the kind of reasoning that have to be called upon when astronomers attempt to answer questions about the evolution of stars.

First I must tell you what a star is and what it is made of. During the past fifty years the study of starlight by the spectrograph and the ad-

vances of modern physics have made it possible to speak of the nature of a star with some confidence. There can be no doubt that a star is an enormous sphere of hot gases with temperatures ranging from some thousands of degrees at the surface to some millions of degrees at the centre.

The spectrograph reveals directly what substances compose the hot gases of the outer layers of stars. It turns out that the outside layers are mostly hydrogen with a little helium and traces of the other known elements like oxygen, carbon, iron and so on. Less direct evidence indicates, on the other hand, that the interiors of stars differ a good deal from one star to another. Some stars like the sun are mostly hydrogen and helium throughout, other stars, like the faint companion of Sirius, must be almost devoid of these light elements.

As regards the proportions of the heavy elements which we call "trace" elements in the stars, it is remarkable that they are present in the sun and stars in almost precisely the same proportions as they are present in the earth and in meteorites. That is to say, common elements like carbon and silicon and iron are also more abundant in the sun and stars than are rare elements like gold and platinum. This suggests that whatever agency produced the solar and stellar mixture must have produced the terrestrial mixture. But with hydrogen and helium the situation is different. These light elements compose by far the greater part of most stars, but they compose only a minor part of the bulk of the earth. If we are to believe that earth and sun were formed from a common medium, we must believe that the earth lost most of its hydrogen and helium in the process of formation.

In some other respects stars differ considerably from one another. Taking the sun to be a medium kind of star, some are ten times smaller, others a thousand times bigger; some ten times lighter, some a hundred times heavier; some ten thousand times less luminous, others ten thousand times more luminous. As these data were amassed, astronomers began looking for correlations which might give more clues as to why (in the words of Kepler) "things were as they were and not otherwise". Some even ventured to look among these correlations for the records which, like the records in the rocks of the earth, would tell the age of a star. If sizes, luminosities and constitution were symptoms of age, would it not be possible to plot the course of evolution?

To illustrate how astronomers have tried to read the records, let me tell you a fable which I made up. A certain ruler had kept two teams of philosophers locked up in ivory towers so that they had never seen growing plants or trees. One day he took them to a forest and proposed

this contest. These are trees, he said, I will give each team a day to observe them and then I will ask you if they are changing at all, and if so, how. The first group watched carefully, saw no changes and concluded that either the trees were not changing or that they were changing so slowly that no conclusion could be reached from a day's observation. The second group spent their day in frenzied activity, not only watching for growth, but measuring and counting everything they could about the trees. Then for weeks they studied their statistics and summarized their conclusions as follows:

"The trees resemble one another in many ways and differ mostly in size. We think it likely that the small trees are young and the large ones old because we see some dead big trees but no dead small trees and we observe that sap is flowing upwards in the trees; and many of the big trees are the same size, whereas the small trees are graded in size; so we suppose that trees are being born all the time, grow relatively rapidly to a certain maximum size and then remain at that size for a long time before they die". Needless to say, the second group of philosophers won the contest.

Now astronomers have learned that they must be like the second group of philosophers. A day in the life of a tree is like the whole period of human history in the life of a star; it produces no measurable amount of steady change. But, given the clues about what makes a star shine and given enough statistics about how many stars are of what size, what mass, what luminosity and what temperature, the astronomers are attempting to postulate a scheme of evolution which could have resulted in the present state of affairs. What success they have had I leave to my colleagues to tell you.

Part II By J. B. Oke

For a great many years it had been known that the central parts of a star must be very hot and highly compressed. It was realized that the energy required to keep a star like the sun shining for billions of years could not possibly be the combustion of materials like coal since these would be hopelessly inadequate for a length of time greater than ten million years. It was only in 1938 that the source of energy in stars was discovered. It was shown that in the hot interior of a star certain nuclear reactions could occur. In particular it was demonstrated that the element hydrogen could be converted into an entirely new element, helium, with the accompanying release of vast amounts of heat and light. We often refer to this nuclear conversion of hydrogen into helium as burning.

although the term "burning" in this sense is astronomical slang and has no relation to burning as applied to combustion of fuels such as wood or coal. Man's experience with the atomic and hydrogen bomb, and nuclear power plants, demonstrates the large amount of energy derivable from these nuclear processes which change one element into another.

It should perhaps be pointed out that astronomical knowledge about the interior of stars played a significant role in the development of the atomic and hydrogen bombs, and is now playing a leading role in harnessing the hydrogen bomb to provide an unlimited supply of nuclear energy for peaceful purposes.

With the discovery of the source of the stars' heat and light, it was now possible to understand the approximate structure of average stars like the sun. Even ten years ago, however, practically nothing was known about the less common but important giant stars, that is stars much larger and more luminous than our own sun.

A year or two ago, astronomers were able finally to discover in considerable detail just what the sun was like. Moreover, they were able to understand the giant stars; and with this understanding the whole field of stellar evolution blossomed. It is only within the last five years that astronomers have been able to ask themselves how stars change in the course of millions or even billions of years, and find any sound and satisfactory answer. It is about these changes in the stars, that is, the evolution of stars, that I wish to talk.

One of the first questions that may be asked is where stars come from. We now are fairly sure that stars condense from filmy clouds of gas and dust that pervade the vast spaces between them. These clouds, which at first are very tenuous, gradually contract and become dense little knots of matter in space. As these knots of gas and dust shrink they begin to warm up, eventually becoming hot. When the temperature is sufficiently high they begin to radiate heat and light from their surfaces. When they reach this stage they have become stars. These new-born stars continue to contract and heat up until the temperature at the centre reaches 25 or 30 million degrees Fahrenheit. At these temperatures, the nuclear reactions already referred to begin to produce energy and the star settles down as a stable sphere of gas like the sun. It may have taken anywhere from 100 thousand to perhaps 10 million years to reach this stage.

Has the star now gone through all the changes to be expected of it? Indeed no. Every star, as it radiates energy is gradually using up its supply of the nuclear fuel hydrogen. Is there enough hydrogen to keep

the stars shining for billions of years? For a star like the sun the answer is yes. The sun has enough hydrogen to keep it hot for perhaps 50 billion years. So far, the sun has used up less than 10 per cent. of its total available supply in its 5-billion-year history. But we must remember that the sun is a very modest star insofar as its consumption of hydrogen is concerned. Some stars consume hydrogen 50 thousand times faster than the sun. These stars will use up their available supply of hydrogen in only a few million years, a time infinitesimally shorter than the age of the sun and earth. From this we can only conclude that since many of these very luminous stars do exist, they must have formed not more than a few million years ago. In fact, it seems hard to believe that stars are not forming even at the present time.

We have now seen that stars do indeed use up their hydrogen fuel in finite lengths of time; in other words stars do grow old. Is there any way to see what happens to them as this occurs? The obvious thing to do is to watch a star for perhaps 40 or 50 years. However, even the most spendthrift star will not change significantly in less than 100 thousand years any more than Dr. Heard's trees would change in a day. This approach is therefore not too satisfactory. Present-day astronomers have other more fruitful techniques, just like Dr. Heard's second group of philosophers. We know that all of the stars in clusters like the Pleiades are of the same age. We also know that the more luminous stars age more quickly than the less luminous ones. Therefore by observing and studying the Pleiades we can actually deduce how the stars change as they grow old. In addition, by performing long and tedious computations involving only known laws of physics, astronomers can also obtain at least a partial answer to the same question. The answer is that stars like the sun in the course of billions of years gradually become larger and larger, and more and more luminous. At the same time the surface temperatures decrease while the interior temperatures may soar to 200 million degrees. The sun will some day be 25 or 50 times as large as it is at present and perhaps 100 times as luminous.

But this swelling up of the stars will come to an end when the supply of hydrogen becomes small. It is true that some stars may be able to get a new but short-lived lease on life by burning helium into carbon by nuclear reactions at very high temperatures, but inevitably they must finally run out of all nuclear fuel. We do not know in detail what happens to them when they reach this stage. We do know that they eventually end as tiny, hot, stars, not much larger than the earth. We know of a great many of these "dying" stars; we call them *white dwarfs*.

PART III BY LEONARD T. SEARLE

Most stars—Dr. Oke told us—burn hydrogen fuel to helium ash; this is what makes them shine. It is this same liberation of energy, occurring when hydrogen burns to helium, that makes a hydrogen bomb so destructive. In the normal stars this reaction is controlled, and a steady stream of energy is released—not an explosive burst.

Dr. Oke stated that this steady burning of hydrogen into helium makes the size and temperature of a star change. In the old age of a star the centre gets hot enough for helium itself to burn—it burns into carbon. The temperature must be about one hundred million degrees before this reaction will begin.

The stars are controlled nuclear reactors; in their deep interiors they turn one element into another; just as the alchemists desired to do, and just as physicists have learned to do in the laboratory. The point I want to make is that not only do stars change with time—evolve as we say—but the very stuff of which the universe is made is changing too.

Careful study of hundreds of stars, has shown that the universe today is made almost entirely of hydrogen gas with a little admixture of helium. All the other elements only amount to a slight impurity of this hydrogen-helium mixture. That's not all. Every moment a star shines it is turning hydrogen into helium and many billions of years ago the primeval universe must have been made of almost pure hydrogen alone.

Out of this primeval hydrogen we know helium is formed; out of the helium, carbon. But what of the impurity elements—the ones that are common on the earth—iron, nickel, even gold and uranium? Are they created in stars from the primeval hydrogen too? The answer seems to be that they are. Before these elements are made the temperatures have to be very high—around a billion degrees or so, much higher than is ever reached in a stable quietly shining star. What is needed is not a steadily running nuclear reactor but a thermonuclear explosion. A heavenly hydrogen bomb. We actually see these occur.

Every few hundred years one of the stars in a galaxy suddenly blows up in an immense explosion. A large fraction of the star is observed to be blown off into space with speeds of thousands of miles per second. In the first week or so the star rapidly increases in brightness and then in the course of the next few months settles down as a faint star again. But in those few months it pours out more light than the sun radiates in many millions of years. We think we understand why this happens but whatever may be the cause such large amounts of energy could only be released in a thermonuclear explosion.

These explosions occur in old stars that have exhausted the supply of nuclear fuel in their centres—they still have hydrogen in their outer layers, where the temperature is not great enough for it to burn. In rather special circumstances the central region which has no fuel left will just collapse and so pull the bottom out from under the rest of the star. The result will be that the outer layers—which still have a lot of hydrogen—will collapse too and heat up so rapidly that the hydrogen will react explosively. The star blows up. The temperature soars to billions of degrees and the impurity elements, iron, nickel and so on are formed and then scattered into space by the force of the explosion.

An event like this is the death blow to a star. A large part of it is scattered into space, the remnant left after the explosion no longer contains hydrogen, it has no fuel left. It is a glowing cinder with nothing to do but cool off. These stars are the white dwarfs. We know of many of these cooling cinders on their way to extinction.They are the corpses of the stars.

So we can follow the life history of a star from its formation out of the interstellar gas until the time when it is a swollen, distended thing almost run out of nuclear fuel. We can recognize the graveyard of the stars. I have told you of one way by which stars come to their ends—but it is probably only one way of many. Much patient research needs to be done and many imaginative ideas will be needed before we will know all about the highly dramatic deaths of the stars.

There is no reason to doubt that our sun will share the common fate and end up a white dwarf—fortunately we can be pretty sure that it won't happen for another fifty billion years or so.

The stars were formed—are even now being formed—out of the gas that pervades the space between the stars—the interstellar gas. The interstellar gas is being replenished by these stellar explosions. The material thrown out by an exploding star mixes with the gas in space and this subsequently is formed into new stars and goes through the whole cycle of evolution again.

You see the consequence of this: if our picture is right the gas from which new stars are formed is being steadily enriched in the impurity elements as time goes on. Each exploding star puts some more impurity elements into the cosmic mixture and the stars most recently formed out of the interstellar gas will contain more iron, for example, than those formed at a much earlier phase in the history of the universe.

In the last few years it has become possible to test this conclusion and with it, to some degree, this whole picture of star origins and evolution. The problem is to pick groups of stars formed in recent times and in

remote times—this can be done now that we understand the life history of a star—and then to measure carefully how much iron there is in the stars of each group. This has been done by several groups of investigators and the results confirm the conclusion: the gas from which stars form is getting richer in these impurity elements as time goes on.

So we see that not only are stars being formed, going through their life cycles and dying, but each successive generation of stars is going through a slightly different cycle because it is made of slightly different material. Where will this end? As far as present knowledge enables us to foresee, the interstellar gas will be used up finally; there will be no fuel for new stars and the hottest brightest stars will have burnt out. The galaxy will be composed of dying red stars and white dwarfs. We know of other galaxies which appear to have reached this old age. And then? Finally the old stars will burn to white dwarfs destined to cool off to darkness.

At present we know of nothing to soften this picture: evolution, like life, appears to be a one-way journey with death at the end of it.

In this remote future hundreds of billions of years from now the stars will become, as they were once thought to be, immutable, unchanging. They will also be very uninteresting; in the meantime mankind is provided with the fantastic beauty of the heavens and the fascination of unravelling the problems presented to us by our changing universe.

A REVIEW OF THE CONSTANT OF PRECESSION

By Donald C. Morton

Publications such as the *American Ephemeris* or the *British Nautical Almanac* list in their tables of astronomical constants the general precession in longitude. They always give its value as $l = (5025.''64 + 2.''22\ T)$ per tropical century, where T is the number of tropical centuries since 1900.0. This particular value, published by Simon Newcomb (1898), has been used for almost sixty years for many astronomical calculations, including all derivations of proper motions. For some time astronomers have suspected that there is a significant error in this value; recent investigations such as that of Morgan and Oort (1951) indicate a correction

$$\Delta l = +0.''75 \text{ per tropical century.}$$

An example of how important this error can be is to be found in the determination by Blaauw and Morgan (1954) of the correction to the absolute magnitudes of the Cepheid variables by means of a statistical study of their proper motions. Of the net correction of -1.5 magnitudes the precession error contributed $+0.2$ magnitudes.

How was this correction to Newcomb's precession found? What caused this error? What are its effects? Why do we continue to use Newcomb's value in the computations for almanacs and proper-motion catalogues? To answer these questions we shall first consider in some detail what are meant by precession and proper motion.

The general precession in longitude is the rate of increase of the mean celestial longitude of a point on the ecliptic, if the point is fixed relative to an inertial frame of reference moving with the sun. An inertial frame is one in which Newton's laws of motion are valid when the only forces acting are inverse-square-law gravitational ones. Mean celestial longitude is the arc of the ecliptic measured from the mean vernal equinox, which is the true equinox corrected for the effect of nutation at the time of measurement.

This general precession has two components which act in opposite directions. The larger, which tends to increase longitudes, is p, the lunisolar precession in longitude; it is the result of the revolution of the mean celestial pole about the ecliptic pole, caused by the gravitational attraction of the moon and sun on the earth's equatorial bulge. The smaller component, which tends to decrease longitudes, is $\lambda\cos\epsilon$, the planetary precession in longitude; it is the result of the secular decrease in the mean

obliquity ϵ of the ecliptic caused by the attraction of the rest of the planets on the earth. Thus

$$l = p - \lambda \cos \epsilon. \tag{1}$$

p, λ, ϵ, and l all change slowly with time.

We wish to determine the values of the precession terms p and λ, which specify the motion of the mean vernal equinox and the mean equator relative to the inertial frame. λ can be derived only from theory using the masses of the planets; p, however, is best found observationally since we do not know accurately the distribution of mass within the earth. All observational methods for calculating p use successive approximations. A particular value is assumed for p and a correction Δp is found by investigating the consequences of this assumption.

One method uses the observed motions of the planets, or better, the asteroids. Discrepancies between observations and predictions based on Newton's laws (corrected slightly by general relativity for the inner planets) are interpreted as a rotation of the assumed inertial frame about the true inertial frame. The former frame corresponds to the assumed value for precession; hence the rate of rotation gives the correction Δp to the luni-solar precession.

The method to be described below uses the observed proper motions of the stars. The right ascension α and declination δ of a star relative to the mean equinox and equator of the time of observation are found for two separate epochs of time. The rates of change of α and δ are the annual variations in the star's position. If the effects of precession are removed from the annual variations in α and δ by subtracting

$$p \cos \epsilon - \lambda + p \sin \epsilon \sin \alpha \tan \delta \quad \text{and} \quad p \sin \epsilon \cos \alpha$$

respectively, we have left the proper motions μ_α and μ_δ of the star relative to the inertial frame. However, if there are errors in p and λ so that they do not represent the motion of the equinox and equator relative to the inertial frame, there will be corresponding errors in μ_α and μ_δ. In practice the proper motions of a star are found by combining many observations by the method of least squares. Nevertheless, any errors in the precession terms give erroneous proper motions, i.e. proper motions which are not relative to the inertial frame. The problem is to find how much of this proper motion is true proper motion relative to an inertial frame and how much is due to errors in precession.

Three factors contribute to this real motion of the star. The first is the star's peculiar velocity, that is the velocity of the star relative to the centroid of stellar velocities in the neighbourhood of the star. This

centroid is called the local standard of rest at the star. The second is the velocity of this local standard of rest relative to the local standard of rest at the sun. It is usually assumed that this velocity is entirely the result of a simple type of galactic rotation in which each local standard of rest moves in a circular orbit perpendicular to the axis of galactic rotation, with an angular velocity which is a function of only the distance from the axis. The third is the velocity of the local standard of rest at the sun relative to the sun itself; it is the reverse of what is called the solar motion. The components of these three velocities on the celestial sphere add together to give the real proper motion of the star.

All these effects on the observed proper motions μ_α and μ_δ, including the influence of erroneous precession, can be represented by equations of the following form used by Vyssotsky and Williams (1948) on p. 63:

$$15\,\mu_\alpha \cos\delta = aX - bY \quad + c\Delta k + d\Delta n + fA + hB + 15\,\mu_\alpha' \cos\delta \tag{2}$$

$$\mu_\delta = eX + dY - cZ \quad + b\Delta n + gA + jB + \mu_\delta' \tag{3}$$

Where a, b, c, d, e, f, g, h, and j are trigonometric functions of the star's position (α, δ). f and g also depend on the galactic longitude l_0 of the galactic centre. μ_α' and μ_δ' represent the sum of the peculiar motions and the observational errors. The factor $15 \cos\delta$ converts a rate of change of right ascension in seconds of time to a rate of change of position in seconds of arc along the great circle tangent to the declination circle. X, Y, and Z are the rectangular components of the solar motion each multiplied by the mean parallax of the group of stars under consideration. A and B are Oort's constants of galactic rotation. It is assumed that the stars studied are sufficiently near the sun to justify the use of the following equations given by Trumpler and Weaver (1953) on p. 565:

$$\mu_l = B + A \cos 2(l - l_0), \tag{4}$$

$$\mu_b = -\tfrac{1}{2} A \sin 2b \sin 2(l - l_0). \tag{5}$$

Here μ_l and μ_b are the proper motions, in galactic longitude and latitude respectively, caused by galactic rotation.

$n = p \sin\epsilon$ is called the general precession in declination and Δn is the correction to n. (6)

On the assumption that any error in ϵ is insignificant

$$\Delta n = \Delta p \sin\epsilon, \tag{7}$$

where Δp is the correction to Newcomb's luni-solar precession in longitude. Note that from equation (1)

$$\Delta l = \Delta p - \Delta\lambda \cos\epsilon = \Delta n \csc\epsilon - \Delta\lambda \cos\epsilon. \tag{8}$$

The quantity Δk is defined by the following relation:

$$\Delta k = \Delta p \cos \epsilon - \Delta\lambda - \Delta e. \tag{9}$$

Here $\Delta\lambda$ is the correction, if any, to Newcomb's planetary precession and Δe is the so-called correction to Newcomb's motion of the equinox. To understand Δe we must consider how right ascensions are observed. Stellar right ascensions are referred to the equinox by the indirect procedure of measuring them relative to a more or less permanent list of 200 to 300 equatorial bright stars. These bright stars, bright enough for daytime observation, are measured relative to the sun which in turn, by observations of its declination, fixes the equinox. Δe is primarily a correction to the motion of the mean origin of the right ascensions of the clock stars relative to the equinox, although other unknown effects such as changes in observing techniques may also contribute to Δe. See Morgan (1941 and 1950), and Newcomb (1906, p. 325).

Since μ_α, μ_δ, a, b, c, d, e, f, g, h, and j are known we can apply equations (2) and (3) statistically to a group of many stars and solve by the method of least squares for the most probable values of the unknowns X, Y, Z, Δk, Δn, A, and B. In so doing we make the reasonable assumption that both $\mu_\alpha' \cos \delta$ and μ_δ', are equal to zero on the average for the group as a whole.

Morgan and Oort (1951), in their discussion of six independent determinations of Δk and Δn by means of the above equations, concluded that the most probable value for Δn is $+0.''30$ per century. The basis of their paper was principally the analysis of the proper motions of some eighty-five thousand stars by Vyssotsky and Williams (1948). New computations of the planetary precession have indicated that Newcomb's value requires no correction. Hence, setting $\Delta\lambda = 0$ in equation (8) gives

$$\Delta l = \Delta n \csc \epsilon = +0.''75 \text{ per century.}$$

A recent determination of Δl by Weaver and Morgan (1956) substantiates this value. From an analysis of the proper motions of 79 Cepheid variables by a somewhat different approach than that indicated above they found

$$\Delta l = +0.''76 \pm 0.''38 \text{(m.e.) per century.}$$

Clemence (1950) obtained from the observed motions of the perihelia of Mercury and the earth a correction

$$\Delta l = +0.''88 \pm 0.''22 \text{(m.e.) per century.}$$

This result should be free from any effect of systematic errors in the proper motions.

There is one difficulty with the determination of Morgan and Oort that has not yet been satisfactorily explained. Combining equations (7) and (9) one finds that Δk and Δn are related by the equation

$$\Delta n \cot \epsilon = \Delta k + \Delta\lambda + \Delta e. \tag{10}$$

If we take Δk from the solution of equations (2) and (3), $\Delta\lambda$ as equal to zero, and Δe from independent observations, we obtain a value for Δn differing significantly from that found directly from equations (2) and (3). Nevertheless the value $\Delta l = +0.''75$ per century is considered the best we have at present.

Now it is possible to understand the origin of this error in Newcomb's precession. Newcomb (1898) analysed proper-motion data by equations similar to (2) and (3) but did not include any terms for galactic rotation. In 1897 when he made the computations the only known systematic motions of the stars other than those caused by the solar motion were the common motions of stars in some clusters. Kapteyn was just about to develop his hypothesis of the two star streams, but Lindblad and Oort were not to publish their work on galactic rotation for almost thirty years. Furthermore, improved observational techniques now give more accurate proper motions, and corrections for effects like the variation of latitude have been applied only since Newcomb's time.

The most serious consequence of this error in precession is the error in all modern proper-motion catalogues, because they have been constructed using Newcomb's precession. It is especially important to remove this error when proper motions are used to find statistical parallaxes. Note, however, that the annual variation of a star's position is not affected, for errors in precession and proper motion are equal but opposite in sign and hence cancel each other at every point on the celestial sphere. A correction to the centennial motions of the perihelia of Mercury, Venus, and the earth is necessary, although this correction is less than the effect of general relativity in each case. A correction to the motions of the nodes of Mercury and Venus is also necessary. For the rest of the planets other errors in their ephemerides make precession corrections insignificant. (See Clemence, 1948).

Although Newcomb's precession is in error there are some rather compelling reasons why we should continue to use it in calculations for almanacs and proper-motion catalogues. First there is still some doubt as to what is a better value to adopt, particularly because of the disagreement with the observed correction to the motion of the equinox. Also any change in the value of an astronomical constant adds much needless labour to the comparison of observations made before and after the

change; instead it is easier, when necessary, to correct published values for a specific application. Moreover, since a general revision of all astronomical constants is being considered, as described by Clemence (1948), much labour would be saved if all constants are corrected at the same time. Such a change probably will be postponed until we have values that can be adopted for as long as a century; hence it is unlikely that a correction will be made for some time to Newcomb's precession for the construction of star catalogues.

At present both the astronomers at the Lick Observatory and the Russian astronomers are independently undertaking large photographic programmes to measure proper motions of stars relative to the external galaxies which, it is assumed, define an inertial frame. Owing to their great distances their proper motions would be too small to be detected for several centuries even if their tangential velocities are as large as their radial velocities. (See Vasilevski, 1954). If these programmes are successful we shall have proper motions relative to an inertial frame and hence also the motions of the equator and the ecliptic.

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THE ORBIT AND SPECTRUM OF A BRIGHT SPORADIC METEOR*

By Ian Halliday

Abstract

Two direct photographs with Super-Schmidt meteor cameras and two spectrograms secured with transmission diffraction gratings have been obtained at Meanook and Newbrook, Alberta, for a bright meteor on October 20, 1955. The trail was photographed between heights of 116 and 82 km. above sea level. The corrected geocentric and heliocentric velocities were, respectively, 57.42 and 42.31 km./sec., with the corrected geocentric radiant at $\alpha = 4^h\ 38^m\ 13^s$, $\delta = +35°\ 37.'2$ (1950.0). Within the errors of observation the velocity is parabolic and an orbit has been computed on this assumption which shows a high inclination to the ecliptic and a small perihelion distance. The orbit is similar to long-period comet orbits.

The spectrum is typical of meteors with large geocentric velocities. A total of 29 features have been identified in the Newbrook spectrogram. A combination of the four photographs shows that the terminal burst of light must have contained at least three distinct maxima.

Introduction

The Newbrook and Meanook Meteor Observatories of the Dominion Observatory were established in 1950 mainly through the efforts of Dr. P. M. Millman, formerly head of the Stellar Physics Division. The observatories have been engaged in routine meteor photography since 1952. Two types of instruments are in operation, Baker Super-Schmidt meteor cameras and aerial cameras equipped with transmission diffraction gratings. The Super-Schmidt cameras are specially designed for a wide field of view and extreme speed. They are used to obtain direct photographs of meteor trails from which heights, velocities, and decelerations in the earth's atmosphere can be deduced when the same meteor is photographed with both cameras. The spectrographs secure photographs of the emission-line spectrum of meteors from which the chemical elements present in the meteor may be identified and information on the physical processes leading to the production of light may be deduced.

Both types of instrument are equipped with rotating shutters which occult the sky according to a predetermined cycle. The meteor trails and spectra are thus broken into a number of distinct segments and since the frequency of the shutter is known, measurement of the lengths of the segments leads to a determination of the velocity of the meteor. The Super-Schmidt shutter is of the focal-plane type and produces 60 breaks

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per second in the meteor trail. The spectrograph shutters are mounted immediately in front of the lens and grating. They produce 24 breaks per second.

On the night of October 19/20, 1955, a meteor of zero magnitude with a very bright terminal burst was photographed with both Super-Schmidt cameras and the terminal burst was photographed with one spectrograph at both Meanook and Newbrook. This spectrum is no. 190 in the world list of meteor spectra (Millman, 1956a).

Observational Data

The observational data are as follows:

Meanook: Lat. 54° 36′ 57″ N., Long. 113° 20′ 45″ W., Elevation 2244 feet. The meteor was seen by Mr. D. W. Corness at $7^h\ 53^m\ 35^s$ Universal Time, October 20, 1955. A persistent train was visible for one minute with binoculars and had assumed an S-shaped line after 30 seconds.

The cameras were operated by Mr. J. M. Grant. The spectrograph employed a Bausch and Lomb replica transmission grating with 80 lines per mm., blazed for maximum transmission at 5500A. in the first order. The camera focal length was 8.0 inches and the focal ratio was f/2.9.

Newbrook: Lat. 54° 19′ 27″ N., Long. 112° 57′ 15″ W., Elevation 2205 feet. Mr. A. A. Griffin was in charge of the photographic equipment at Newbrook. The spectrograph grating had 400 lines per mm., blazed for 5000A. in the first order.

The emulsions used were Kodak single-coated blue-sensitive X-Ray sheet film for the Super-Schmidt cameras and Kodak Aero Super XX roll film for the spectrographs.

The Super-Schmidt Photographs

The Super-Schmidt photographs of this meteor are reproduced in figures 1 and 2. The original negatives are caps of a sphere with chordal diameters of about seven inches and radius of curvature eight inches. The film is moulded to this shape by a heat treatment before exposure in the camera and must be accurately held to this shape by a vacuum system in the camera while the exposure is in progress. A copying camera, also specially designed by Dr. James G. Baker, is used at the Dominion Observatory, Ottawa, to copy the original spherical negative onto a flat glass plate. Reproductions can then be made from these plates which are also used for accurate measures.

Both photographs show 42 segments on the meteor trail. The terminal burst consists of the last three segments which are heavily overexposed. Between the segments of the meteor trail a fainter line can be detected.

FIG. 1—Super-Schmidt meteor photograph from Newbrook. The meteor moved from left to right. North is at the top. The dark circular region in the centre is caused by the central hub of the rotating shutter, and constitutes a blind spot for the cameras.

This is due to the meteor wake, a luminosity behind the meteor which lasted for about 0.01 seconds and was bright enough to be photographed each time the shutter re-opened. The enduring train is weak by comparison and cannot be detected on the photographs.

In addition to the meteor many interesting astronomical objects can be identified on these photographs. The Newbrook photograph shows the spiral nebula in Andromeda, the Milky Way in Cassiopeia, and several galactic clusters. The companion photograph from Meanook shows the spiral galaxy in Triangulum, the famous double cluster in Perseus, the Pleiades, and a large diffuse nebula within our own galaxy.

FIG. 2—Meanook photograph corresponding to figure 1.

Height and Velocity of the Meteor

It is possible to compute the height and velocity of the meteor from the two Super-Schmidt photographs together with the known time of observation and the locations of the observing stations. The method followed for this meteor has been described by Whipple and Jacchia (1957). Only the results will be considered here.

The extreme range in height of the photographed portion of the trail is from 116.08 km. (72.13 miles), down to 82.30 km. (51.14 miles), computed above the International Spheroid (sea-level). The range in height of this meteor is quite normal for fast meteors (Lovell, 1954).

The observed velocity at the mid-point of the trail was found to be 58.52 km./sec. (36.36 miles/sec.), and the deceleration caused by atmospheric resistance at this point was 0.89 km./sec. Small corrections must

be applied to the observed velocity to allow for atmospheric resistance, rotation of the earth, and gravitational attraction. The corrected geocentric velocity was 57.42 km./sec.

Radiant and Orbit

The radiant of a meteor is the point in the sky from which the meteor appears to come. It can be obtained from two photographs at different stations by determining the point of intersection of the two trails, since it must lie on each trail. The radiant position is not appreciably affected by atmospheric retardation but must be corrected for diurnal aberration and the earth's gravitational attraction. The corrected geocentric radiant position for this meteor is at right ascension $4^h\ 38^m\ 13^s$, declination $+35°\ 37.'2$, in the 1950.0 co-ordinate system. This is a point in Auriga, close to the boundaries of Perseus and Taurus.

For purposes of orbit computation the significant data are the position and velocity of the meteor at any instant. The orbit is governed by the attraction of the sun so the geocentric velocity must be converted to heliocentric velocity, by allowing for the known speed of the earth in its orbit. The computed heliocentric velocity was 42.31 km./sec.

The orbit of any object in the solar system must be an ellipse, parabola or hyperbola, with the sun at one focus. There has been considerable controversy as to whether some sporadic meteors move in hyperbolic orbits or whether all meteor orbits are really elliptical. Old observations indicated many hyperbolic orbits but modern, more precise measures with good photographs, and also radio methods, have failed to reveal any orbits which are unquestionably hyperbolic.

The heliocentric velocity corresponding to parabolic velocity at the earth's distance from the sun on October 20, 1955 is 42.19 km./sec. The computed meteoric velocity thus exceeds the parabolic limit by 0.12 km./sec. This cannot be considered as appreciably greater than the errors of measurement, hence no significance is attached to the fact that the velocity implies a hyperbolic orbit.

In such cases, when dealing with comet orbits it is customary to assume that the orbit is a parabola. The orbit so computed will be practically identical with an ellipse of high eccentricity in the vicinity of the earth and the sun. This has been done for the present meteor, and the elements are given in Table I.

The orbit is shown in figure 3 relative to the orbits of Mercury, Venus and the earth. The meteor was approaching the sun when it collided with the earth, and would have approached to within less than half the distance of Mercury from the sun, if it had not been intercepted by the earth.

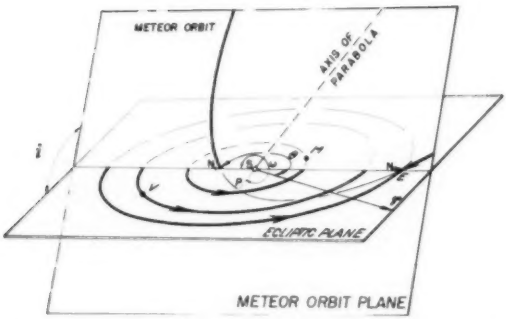

FIG. 3—The meteor orbit. The orbital plane of the meteor and its intersection with the ecliptic are shown. The sun is at S. The positions of Mercury, Venus, and the earth are shown by the letters M, V, and E. P is the perihelion point of the meteor orbit and N_1 and N_2 are the ascending and descending nodes. The meteor collided with the earth at the descending node, N_2. The orbital elements i, ω, θ, are indicated in the figure. Note that ω is measured in the plane of the meteor orbit and θ in the ecliptic plane. The direction of the first point of Aries is shown by Υ.

TABLE I

ORBITAL ELEMENTS OF THE METEOR

e, eccentricity, by definition of a parabola,	1.00
q, perihelion distance,	0.164 A. U.
i, inclination to the ecliptic,	129° 20′
ω, argument of perihelion,	312° 07′
θ, longitude of the ascending node,	206° 08′

The fact that the inclination exceeds 90° means that the meteor was in a retrograde orbit, i.e. its motion was clockwise as viewed from north of the ecliptic. The high inclination rules out the possibility that the meteor had been perturbed into a slightly hyperbolic orbit by passing near some other planet, for it would have been far above the general plane of all the outer planets at their distances from the sun.

A parabolic or hyperbolic orbit is not periodic. If the true orbit in this case were a very elongated ellipse, then the period would be quite long, likely at least several hundred years. Consequently if the orbit does correspond with that of some long-period comet it is not likely to have been observed in the era of accurate astronomical observations. It is not surprising, then, that the orbit does not agree with the elements of any well-known comet.

The Meteor Spectrum

Since the path of a sporadic meteor, such as this one, may appear in the sky inclined at any angle to a fixed direction, the spectral lines may be inclined at any angle to the dispersion of the spectrograph. The most favourable case is that in which the meteor path is perpendicular to the direction of the dispersion. For camera G, at Meanook, this inclination was only 9°, while for camera H, at Newbrook, the inclination was 68° which is much more favourable. The average dispersion in the first order is about 570 A./mm. for camera G and 111 A./mm. for camera H. The Newbrook spectrum represents quite high dispersion for meteor spectra.

The Newbrook spectrum is reproduced in figure 4. Because of the low dispersion and particularly because of the low inclination of the lines to the dispersion, the Meanook spectrum is of little value and will not be described in detail. The general appearance of the spectrum is similar to other spectra of fast meteors, such as Perseid spectra (Millman, 1953, 1956b), or an Orionid spectrum (Vyssotsky, 1940). The ionized lines of calcium, magnesium and silicon are fairly strong relative to the neutral lines of sodium and magnesium.

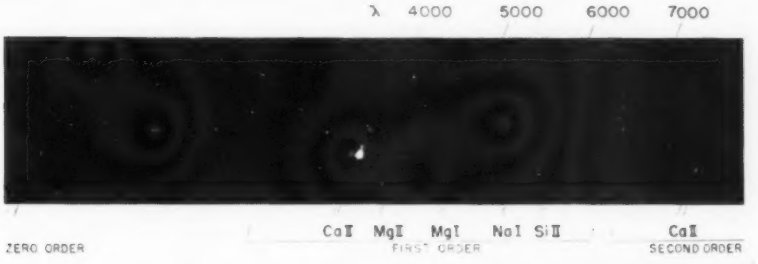

FIG. 4—Meteor spectrum no. 190 photographed at Newbrook. The stronger features are identified beside the photograph.

The spectrum consists of the zero order, a complete first order, and the *H* and *K* lines of the second order. Other features which might have been strong enough to record in the second order would have fallen outside the field of the camera. The spectrum appeared very close to one edge of the film and is not in good focus at the zero order or violet end of the first order. The focus is good at the extreme corner of the field where the second order *H* and *K* lines appear.

Most of the light is concentrated in the final segment. Seven earlier segments of the direct image or zero order can be traced on the original

negative, most of them very faintly. Most of the spectral features appear only in a burst during the last third of the final segment. The first order *H* and *K* lines, which are the strongest features, show the end of a previous burst at the beginning of the last segment and the start of a burst at the end of the preceding segment. This brightening at the end of the second last segment is obvious in the zero order as well but the burst at the beginning of the final segment is peculiarly absent in the zero order. The S-shape of the *H* and *K* lines in the first order is caused by a combination of coma in the camera lens and the effects of the rotating shutter.

The spectrum was measured for wave-length determinations in the following manner. Linear interpolation was first applied between two known features and a smooth correction curve was then drawn from the differences between the known wave-lengths and the interpolated values for several of the strong features. When these corrections are applied to the interpolated values for every line the final wave-lengths are obtained.

A total of 29 features were measured with the results tabulated in Table II. Successive columns show the measured wave-length, the atom

TABLE II

WAVE-LENGTHS AND IDENTIFICATIONS

λ measured	Atom or Ion	Mult. No.	λ lab.	Excit. Pot.	Intensity
3724.4–3755.1*	Fe I	5		3.35	weak
	Fe I	21		4.20	
3819.1–3843.6*	Fe I	4		3.23	medium
	Fe I	20		4.1	
	Mg I	3		5.92	
3850.2–3864.5*	Fe I	4		3.20	medium
	Fe I	20		4.20	
	Si II	1		10.03	
3876.2	Fe I	4	3878.6	3.27	weak
	Fe I	20	3872.5, 3878.0	4.16	
3934.2	Ca II	1	3933.7	3.14	very strong
3967.2	Ca II	1	3968.5	3.11	very strong
	Fe I	43	3969.3	4.59	
4004.9	Fe I	43	4005.2	4.63	weak
4027.9–4048.8*	Fe I	43		4.53	weak
	Mn I	2		3.06	
4056.9–4076.0*	Fe I	43		4.61	weak

TABLE II—*continued*

λ measured	Atom or Ion	Mult. No.	λ lab.	Excit. Pot.	Intensity
4130.5	Si II	3	4128.1, 4130.9	12.78	weak
	Fe I	43	4132.1	4.59	
4143.8	Fe I	43	4143.9	4.53	weak
4227.2	Ca I	2	4226.7	2.92	medium
4250.5	Fe I	42	4250.8	4.45	weak
	Fe I	152	4250.1	5.36	
4259.1	Fe I	152	4260.5	5.29	very weak
4272.5	Fe I	42	4271.8	4.37	medium
	Fe I	152	4271.2	5.33	
4308.3	Fe I	42	4307.9	4.42	weak
4325.6	Fe I	42	4325.8	4.45	weak
4369.4	Fe I	518	4369.8	5.86	very weak
4382.2	Fe I	41	4383.5	4.29	medium
4405.7	Fe I	41	4404.8	4.35	medium
4427.4	Fe I	2	4427.3	2.84	weak
4457.3	Fe I	68	4459.1	4.93	very weak
	Ca I	4	4454.8, 4455.9	4.66	
4466.3	Fe I	350	4466.6	5.58	very weak
4481.0	Mg II	4	4481.2	11.58	strong
5170.8	Mg I	2	5167.3, 5172.7	5.09	medium
5184.0	Mg I	2	5183.6	5.09	medium
5890.1	Na I	1	5890.0	2.10	strong, D_2 measured, blended with D_1
6346.7	Si II	2	6347.1	10.03	medium
6371.7	Si II	2	6371.4	10.02	weak

*These features were measured as broad unresolved blends extending between the indicated wave-lengths.

or ion responsible for the line, the multiplet number in Miss Moore's (1945) tables, the laboratory wave-lengths for the sharp features, the excitation potential of the upper state above the ground state for the atom or ion, and a comment on the intensity of the feature. Some of the features are broad blends of several lines or several multiplets. Many are too faint

to reproduce well. With the high dispersion of this spectrogram the measured wave-lengths should be better than in most previous meteor spectra. No evidence for lines of ionized iron, Fe II, was found.

It might be expected that the sodium *D* lines would be resolved with this dispersion into the two components D_1 and D_2. This has not been achieved, but microphotometer traces of the line indicate that the peak intensity corresponds to the D_2 line with a wing on the red side caused by the D_1 line.

The relative intensities of the *H* and *K* lines of Ca II were measured with the microphotometer. The film had been calibrated with a rotating sector in front of the slit of a Hilger quartz-prism spectrograph, so that the calibration curve could be obtained at any desired wave-length. Once the calibration curve had been determined it was used in a direct-reading recording intensitometer to give traces on a true intensity scale.

The *H* and *K* lines were measured at several points along the length of the strong segment in both the first and second orders. Relative intensities were determined by measuring the areas under the intensity profile. The individual values of the ratio of *K* to *H* ranged from 1.40:1 to 1.65:1 with a mean value of 1.51:1. Since the theoretical intensity ratio is 2:1 the departure from the theoretical value appears real and suggests that an appreciable amount of self-absorption occurs within the volume of gas that is radiating at any given instant. The contribution of the suspected line of neutral iron blended with the *H* line would be much too small to affect this result. The instrumental sensitivity is decreasing toward shorter wave-lengths in this spectral region but the change in an interval of only 35 A. could scarcely cause such a departure from the expected intensity ratio of the *K* to *H* lines.

The Light Curve

From the four photographs of this meteor it is possible to establish the complex nature of the light curve during the twentieth of a second for which the terminal burst lasted. There must have been at least three distinct maxima of light intensity, and part of each maximum was caught by the Super-Schmidt cameras. A schematic reconstruction of the light curve during the terminal burst or flare is shown in figure 5. The ordinates are rough intensity estimates, and the curve has been drawn with all three maxima of equal intensity. The intervals during which each camera was actually exposing on the meteor trail are indicated.

Visual observers of meteors will recognize the overall light curve of this meteor as one of the common types. The resolution of the terminal burst into three separate peaks would not be achieved by the eye. In a

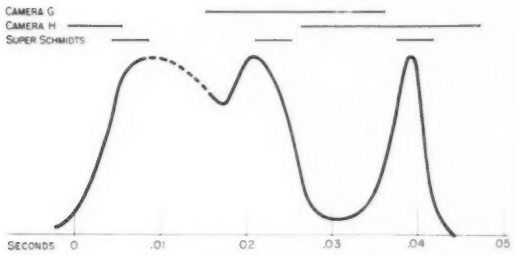

FIG. 5—Schematic light-curve of terminal burst. The intervals when each camera was exposing are indicated by solid horizontal lines above the curve. The dotted portion of the curve is for a short interval when all cameras were occulted by their shutters.

discussion of meteor flares Jacchia (1949) shows that durations of 0.02 seconds are commonly found. The terminal burst of this meteor is quite similar to meteor no. 778 in Jacchia's figure 4, except that the three maxima are crowded into half the time interval of the three flares on no. 778.

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CANADIAN SCIENTISTS REPORT

VII. SOLAR RADIO ASTRONOMY

By Arthur E. Covington*

Systematic studies of solar radio emission have been undertaken in several countries during the past ten years, and sufficient evidence has now been accumulated to show that these emissions may provide much needed measures of solar activity. Solar indices, such as sun-spot number and the area of sun-spots, are well established, and in the case of the Zurich numbers, extend back to 1749. In addition to their intrinsic solar interest, the Zurich numbers have been successfully used in studying solar-dependent phenomena on the earth's surface in which it is desirable to have an indication of the variable solar energy. In this case, strange as it seems, the presence of dark sun-spots was interpreted as an increase of solar emission. In the geophysical field, variation in solar activity is reflected in a variation in the number of free electrons in the ionosphere, the ozone content in the air, and the frequency of occurrence of aurorae and of magnetic storms. Present-day geophysical research has created a need for a more accurate measure of primary solar energy, and within the next few years much attention will be given to the possibilities presented by the observation of solar noise.

The Solar Spectrum

A much simplified graph of the solar energy received on a section of the earth's surface one metre square, for various wave-lengths ranging from the ultra-violet to long radio waves, is shown in figure 1. The complete range of wave-lengths shown in the abscissa of the graph cannot be observed on the earth's surface because the upper atmosphere forms natural barriers at different wave-lengths. On the earth's surface only two transmission regions are observed, one containing the light and heat waves, and the other containing the radio waves. In the graph, these two transmission bands are the clear regions between the hatched absorption bands.

The intensity of the continuous background spectrum in the optical region, after correction for the dark absorption lines, can be fitted readily

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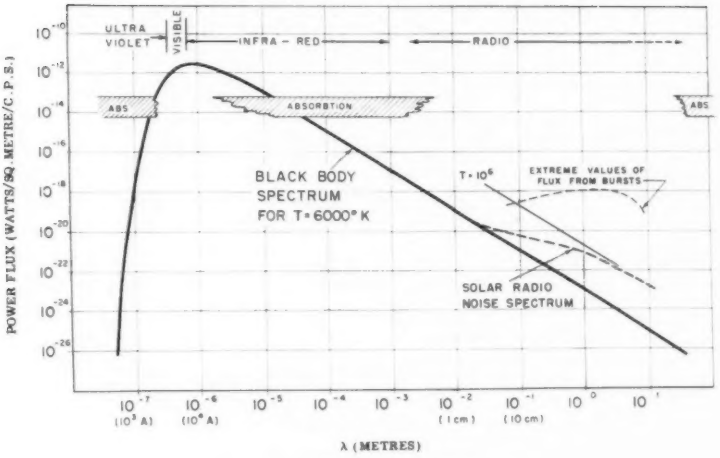

FIG. 1—Graph of the solar spectrum.

to a theoretical radiation curve of a black body at a temperature of 6000°K., as shown by a solid line on the graph (figure 1). However, in the radio spectrum, the observed curve shows a large excess over the theoretical radiation curve for 6000°, which can be explained only in terms of temperatures ranging from values of 10,000° to tens of millions of degrees. The use of a temperature to describe these deviations from the black body curve has led to the use of an equivalent temperature and is the means whereby portions of an ideal black body radiation curve may be used to measure the observed intensity over a small range of wave-lengths. Another unit for measuring the radiant solar flux, already used as the ordinate in figure 1, is the power in watts falling upon a given area within a given band of wave-lengths.

The intense radio emission is explained in terms of an electro-magnetic radiation from the electrons in the highly ionized outer solar atmosphere. This region of the sun extends from the visible disk—the photosphere—to a distance of several solar radii and separates into at least two layers: the chromosphere lying just above the photosphere, and the corona, again lying outside the chromosphere. The minimum equivalent temperature observed over a range of metre wave-lengths is about 1,000,000°K. and has been directly related to the kinetic energy of the free electrons. This radio evidence is one of several indications that the electrons are moving as though immersed in a medium of this high

temperature. The basic radio emission associated with the minimum temperature of the corona is produced by collisions of electrons with ionized hydrogen atoms in the continual jostling arising from their heat motions. The resultant intensity, as the sum of many individual waves occurring in a random manner, changes from moment to moment. This variability, when converted into sound waves by a radio receiver and loud-speaker is evident to our senses as a hissing sound, and has resulted in the name "solar radio noise". The strength of the emission is related partly to the kinetic energy of the electrons and partly to the number of electrons per cubic metre, or the electron density. Other modifying solar features—in some cases acting as natural radio amplifiers—are the magnetic fields and jets of moving gases in the vicinity of sun-spots. These give rise to an ordering effect of the individual electrons and consequently produce greatly enhanced radiation. In contrast to the thermal emission, these latter radiations are referred to as non-thermal emission.

The total energy received on a unit section of the earth's surface is exceedingly important and has been named the solar constant. It is represented by the area under the spectrum-curve shown in figure 1. In the optical region of the spectrum, the energy originating from the outer solar atmosphere and falling upon the earth is very small, even though the kinetic temperature is very high. These outer gases are very thin and radiate efficiently only in the radio region of the spectrum. Most of the energy in the optical region arises from the cooler and denser photosphere, and a value of about 1.5 kilowatts for every square metre of the earth's surface has been measured. In the radio region, the estimated energy amounts to about one part in 10^{11} of that contained within the optical spectrum. The extension of the solar spectrum from the optical to the radio region has not led to a revision in the accepted magnitude of the solar constant. In relation to the quantity of heat received at the earth, radio emissions are insignificant, but may be very important to our understanding of how this energy is released by the sun. In this sense, the relation of the solar radio emission to the total solar energy output is similar to the ratio of the radio power of the ignition noise from an automobile to the mechanical power produced by the engine.

Radio Observations

The simplest, and hence most frequently used method of observation is the collection of the radio emission in a restricted band of wave-lengths from the whole solar disk by an antenna or "radio telescope" having a cone of acceptance of several degrees. This band of wave-lengths is re-

stricted further when the emission is amplified by a sensitive radio receiver or "radiometer", and finally the amplified solar emission is converted into a direct current for operation of a paper-strip recording meter. Early investigators employed equipment of this type, the choice of an operating wave-length being determined principally by the availability of components from existing radar equipment. Commencing in 1942, observations have been made on various occasions at about a dozen discrete wave-lengths throughout the radio spectrum, and the resulting curves of solar flux as a function of time have provided basic information for testing hypotheses on the generation and escape of radio waves from the quiescent sun. The records, in addition to indicating the daily level of emission, may display complex variations of amplitude for short periods of time. These have become known as bursts of solar noise; sometimes they take the form of a single rise and fall of intensity and are called single bursts, but more frequently they occur in great profusion, one superimposed upon the other, with various strengths and durations. In general, metre wave-length observations show much more burst activity than those of the shorter centimetre waves. Records at the various observatories are examined to give a numerical description of the solar flux, and the results are expressed in at least three categories: (1) the mean value of the minimum flux observed for the day; (2) the variability of the emission above this mean, and (3) any burst activity of outstanding nature.

The Radio and Electrical Engineering Division of the National Research Council, Ottawa, has placed particular emphasis upon solar observations at 10-centimetre wave-length. Various surveys of the solar emission on this, as well as other discrete wave-lengths throughout the radio spectrum, have been conducted at other observatories (Pawsey and Bracewell, 1955), and have revealed complex intensity variations as a function of time, as previously noted. Fortunately, the essential variations may be observed by examining the solar radio emission in two widely different wave-length bands which, on the basis of past and present observations, may be designated by the specific wave-lengths, 10 cm. and 150 cm. The appearance of bursts on these two wave-lengths is generally different; the shorter wave-length bursts occur occasionally and change smoothly, while the longer wave-length bursts are very numerous and show many rapid changes of intensity (Covington and Medd, 1949). Such an arbitrary division hardly does justice to the vast amount of detailed information available, and is undertaken only as a convenience to provide two groups of observations with entirely different

characteristics. The desirability of obtaining complete world coverage on these two wave-lengths has been recognized by the International Scientific Radio Union.

Analysis shows that the solar atmosphere may be regarded as a series of layers, and at a given wave-length of observation only certain layers contribute to the resultant intensity. The controlling factor is the electron density which, at a height depending on the wave-length, creates a reflecting layer in the same manner as a reflecting layer is formed in the earth's ionosphere. Radio waves of the specified wave-length originating below this solar reflecting layer are quickly attenuated in the dense atmosphere of electrons, while waves originating in layers above, travel freely outwards through the thin atmosphere. It is further found that waves of the critical wave-length are very efficiently radiated from the vicinity of the reflecting layer. If the observing wave-length is made shorter, the reflecting layer is situated at a lower level so that emission from a lower region of the ionized gas will be observed. Thus observations at a given wave-length provide information about certain regions of the solar atmosphere—the longer wave-lengths for the outer layers, and the shorter wave-lengths for the inner layers. In certain regions of the solar atmosphere the physical characteristics of density and temperature of the gas change rapidly, so that the overlying layer will be semi-transparent, partly absorbing the emitted radiation from below, and at the same time emitting a radiation of its own.

Radio emission from the quiet sun in the metre band (150 cm.) may be regarded as originating from the outer corona at levels given by radii of about 1.4 units expressed in terms of unit radius for the photosphere. The ten-centimetre radiation originates partly from a deeper layer, at the base of the corona, with $r = 1.05$, and partly from the outer corona. This radiation, originating as it does in two layers, will consequently be very sensitive to the physical difference of the two layers. One-centimetre emission is mainly from a still deeper layer, the chromosphere, with negligible contribution from the corona; and finally, the short optical wave-length emissions originate almost completely in the photosphere, the bottom of the solar atmosphere.

In the optical region of the spectrum emission from the outer corona is so weak that it can be measured only under the special conditions of a total eclipse, while emission from the inner corona and chromosphere, although seen during an eclipse, may now be isolated at any time by special instruments called, respectively, the coronagraph and the spectroheliograph. The importance of the radio observations perhaps lies in the ease with which emission from the outer rarified gases of the sun may

be measured. In addition, radio observations can be made throughout the day regardless of the presence of clouds or rain, and, with international co-operation, a very small number of participating stations provide a continuous watch on the sun.

Radio Observations at N.R.C., Ottawa

Daily observation of 10.7-cm. emission from the sun, taken in Ottawa, has now entered the tenth year. A typical record with a four-foot parabolic reflector, for the afternoon of January 20, 1957, is shown in figure 2.

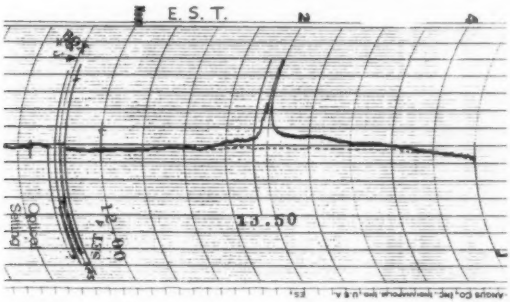

FIG. 2—Recording of 10.7-cm. solar radio flux for afternoon of Jan. 20, 1957.

By means of automatic equipment, monitoring of the emission now commences at sunrise and continues until sunset. Near local noon each day the sensitivity of the radiometer is determined by an operator, so that the steady flux for the whole day may be calculated. The significance of day-to-day variations of this quantity has been discussed in detail, and it has been shown that the changes may be related to radio emission from hot spots in the solar corona. During the ten-year period, a plot of the monthly average solar flux shows a threefold variation (see figure 3). The minimum value of 70 flux units was observed for the year 1954 (a period of sun-spot minimum), and may be taken to represent the intensity of emission from the undisturbed solar atmosphere. The increased intensity, both before and after this period, coincides in the first case with the declining sun-spot activity from the previous peak in 1947, and in the second case it corresponds to the growth of the present sun-spot activity.

The question of the variability of solar emission is important. Solar emission in the visible and infra-red regions certainly shows no such large variation during the sun-spot cycle, while the intensity of the solar ultraviolet radiation, as measured by the ionization density produced in the

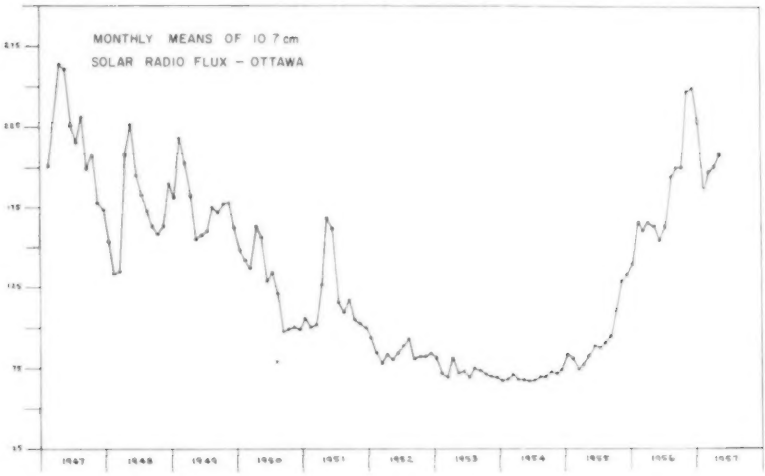

FIG. 3—Monthly averages of 10.7-cm. solar flux, 1947 to 1957.

earth's upper atmosphere, has been found in the cycle previous to the past one to vary by a factor of two. The change in magnitude of both the ultra-violet and the slowly varying ten-centimetre radio emission is comparable, and may have significance in relation to the variable source of solar energy. It is important that both emissions are associated with the same bright solar region seen in hydrogen and ionized calcium spectroheliograms (Covington and Broten, 1954; Dodson, 1954), and this suggests that the ten-centimetre flux could be considered, at least, as an index of ultra-violet radiation. This solar radio index is a direct measure of a solar quantity, and unlike the ionospheric electron densities, needs no correction for particle emission. Any possible particle emission, together with the associated temporary increase in ultra-violet emission, has already been included in the ten-centimetre burst phenomena.

Solar Noise Bursts

As was mentioned previously, a burst of solar noise is recognized by an enhancement of emission above the daily level. In figure 2, two types of burst may be recognized from the record of January 20: a long rise-and-fall, with a more intense impulsive burst superimposed; while in figure 4 only the impulsive burst appears. The most intense bursts of solar noise are observed almost simultaneously throughout the solar

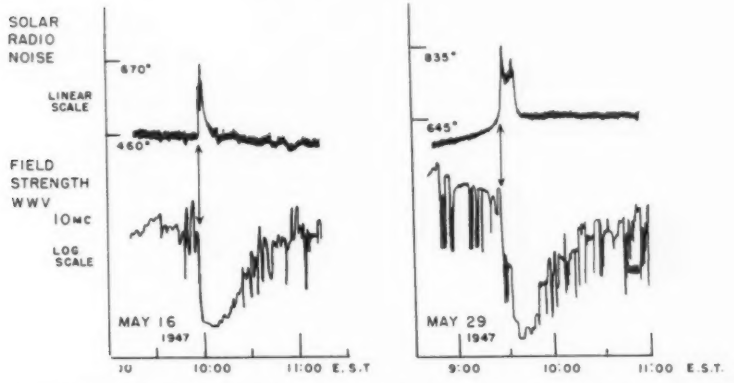

FIG. 4—*Upper Trace*: Selected 10.7-cm. solar noise bursts. *Lower Trace*: Associated interruption of WWV transmission.

spectrum and are usually associated with the appearance of solar flares. In the optical region, the solar flare is recognized as an intense brightening of the pre-existing bright regions around sun-spots seen in the monochromatic light from ionized hydrogen or calcium atoms. Nearly all of the bursts in the ten-centimetre region have been shown to be associated with solar flares—the burst and flare commencing within a few minutes of each other. In the metre wave-lengths only the more intense bursts, or outbursts, show this flare association; the other more numerous burst features present in this region are apparently not duplicated in the microwave region, but are, presumably, also related to a flare and its associated active region in some complex but as yet unknown manner.

The time of commencement of some outbursts has shown a tendency to vary with the wave-length of observation—the longer wave-length bursts arriving after the shorter wave-length bursts—with intervals of time ranging from seconds to several minutes. This time delay has been interpreted as a delay in the excitation of the various layers of the corona. At the time of the flare, large amounts of energy in all forms are suddenly released. Solar material is ejected from the photosphere, exciting first the lower levels responsible for the short-wave emission, and then the upper levels responsible for the metre wave-length emission. The large intensities observed are sometimes hundreds of times the emission from the whole solar disk, and indicate that very special non-thermal mechanisms are responsible for the generation of the radio noise.

Construction of radio equipment capable of making observations in rapid succession over a large portion of the radio spectrum from 1 metre to 10 metres has enabled part of this time delay to be studied more easily. The observations from the equipment are called "dynamic spectra" and have enabled comprehensive results to be obtained of what would be otherwise a very complicated problem in instrumentation. The difference in time of burst commencement at the different wave-lengths has enabled velocities of ejection to be found. Some velocities are a small fraction of the velocity of light and have been attributed to the ejection of cosmic ray particles; other velocities correspond to the ejection of auroral particles which take about a day to reach the earth. The existence of bursts characterized by a fundamental frequency and overtones has also been revealed and has provided an important clue for theoretical work. When these techniques are employed throughout the whole radio spectrum and the complete radio results related to the optical phenomena, a better classification of flares will be possible.

Geophysical Effects of Flares

The effects on earth of a solar flare are manifold. In the unusually intense flares which occur only a few times in the eleven-year sun-spot cycle, clearly recognized major disturbances in several fields have been observed and are attributed to the liberation of energy from the solar eruption. These are shown pictorially in figure 5. The light and radio waves both travel with a speed of approximately 3×10^5 kilometres per second; the cosmic rays with a slightly lower velocity. All are recorded directly on appropriate instruments. The ultra-violet light is measured indirectly by observing effects arising through the formation of an absorbing layer of ionization in the sunlit portions of the earth's upper atmosphere; as observed both by the interruption of short-wave radio circuits (for example, see the lower curve of figure 3), and by a small characteristic variation in the direction in which the compass needle points. Some of the solar particles ejected during the flare travel much more slowly than light, and usually strike the earth's atmosphere after a travel time of about one or two days. The earth's magnetic field guides the incoming ionized particles into many paths, some of which end on the dark side of the earth. Here, upon striking the earth's atmosphere, the ionized particles give rise to an auroral display. As in the case of the temporary ultra-violet light emission, the disturbed ionosphere interrupts radio communication and causes the compass needle to experience violent displacements. During the more numerous weaker flares, cosmic-

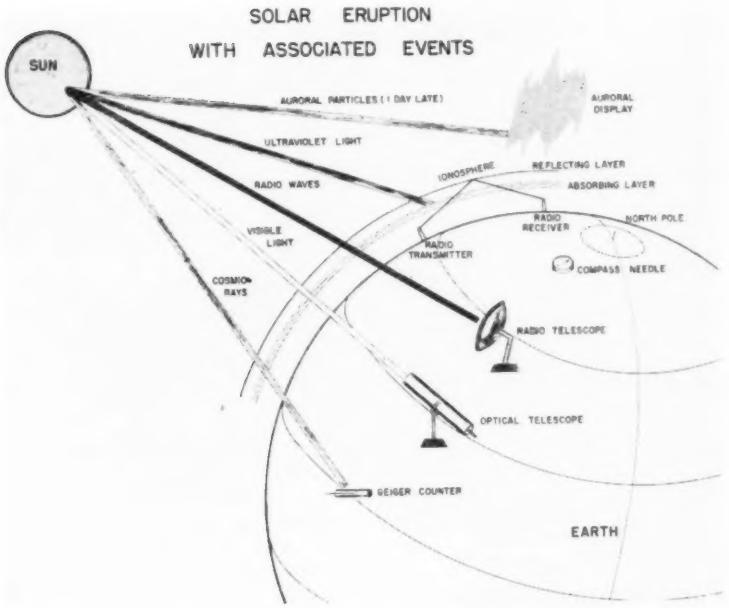

FIG. 5—Representation of solar emission during intense flare.

ray emission appears to be absent, or very weak, while the remaining effects appear in various combinations and patterns.

During the present sun-spot cycle, and particularly during the International Geophysical Year (1957–1958), extensive recording of the optical flares with the associated solar noise emission, ionospheric and geomagnetic events, will further the investigation of the important sun-earth energy relationships.

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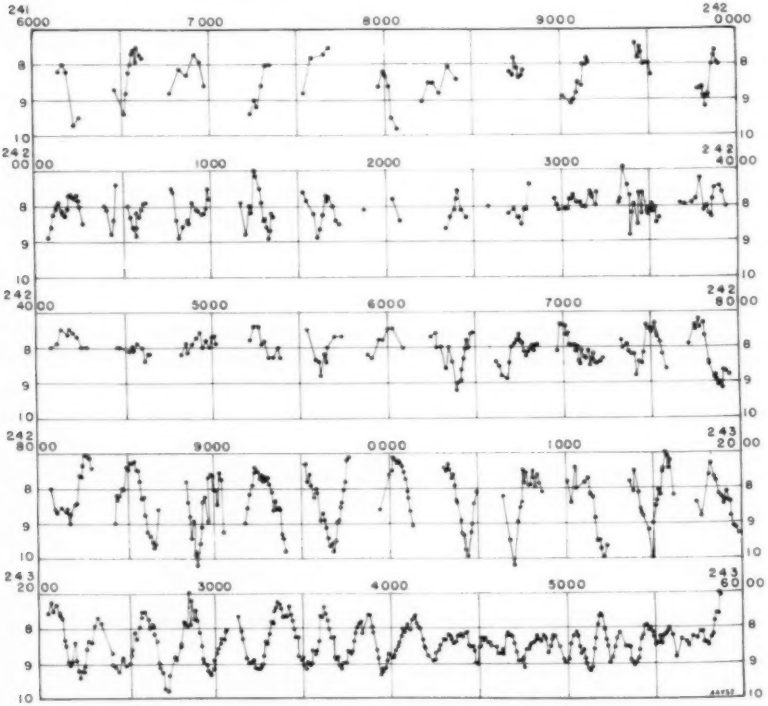
VARIABLE STAR NOTES

American Association of Variable Star Observers

By MARGARET W. MAYALL, *Director*

082405 RT Hydrae. The peculiar and erratic variations of RT Hydrae are an enigma which will probably not be solved until after the variable has been thoroughly observed for at least another 50 years.

The star was studied by D. J. K. O'Connell, S.J. (*Harv. Bull.*, 890), who analyzed its photographic and visual light curves between 1899 and 1932. Father O'Connell found some indication of the RV Tauri-type alternation of deep and shallow minima, and concluded that RT Hydrae appeared to be a link between the RV Tauri-type variables and the long-period variables like R Centauri and R Normae, which also have alternating deep and shallow minima.



082405 RT Hydrae. Mean light curve, 1903–1957.

The mean light curve shown here is plotted from 10-day mean values of visual observations from 1903 to 1957. The points before J.D. 2,419,400 are from observations made by Harvard astronomers (*Harv. Ann.*, 63 and 79), and following that, are from observations made by members of the A.A.V.S.O., supplemented in later years with observations by the members of the Royal New Zealand Astronomical Society.

For the first 6,000 days, from J.D. 2,416,000 to J.D. 2,422,000, the over-all variation was about two magnitudes, from 7½ to 9½. During the next 1,500 days, the range decreased to about one magnitude. The star was very irregular for the next couple of thousand days, and gradually increased its total range, until after J.D. 2,428,000, in 1936, when it reached nearly three magnitudes. For the next 6,000 days, the light curve of RT Hydrae was very similar to other long-period variables with small ranges. Its mean period was about 255 days. In 1950 the maxima showed an indication of double peaks, and in 1952 a decided change in the form of the curve took place. Following a long interval between minima (about 290 days), RV Tauri-type characteristics again became pronounced, and double maxima were separated by alternating deep and shallow minima. The range of variation was between the 8th and 9th magnitudes. The most recent observations plotted on the curve show a sudden rise to the 7th magnitude in May 1957.

The following table lists the dates of maxima and minima of RT Hydrae since 1949, and is a continuation of the dates determined by Leon Campbell and printed in his "Studies of Long Period Variables", published by the A.A.V.S.O. in 1955. The dates of maxima and minima following J.D. 2,435,450 are subject to revision, pending inclusion of observations from the New Zealand observers.

RT Hydrae has been very well observed since 1947. It is to be hoped that observers will continue to watch it in the future, and perhaps some day we will know more about its vagaries.

DATES OF MAXIMA AND MINIMA OF RT HYDRAE

Max.	mag.	diff.	Min.	mag.	diff.
33100	—	256	33244	9.2	226
33356	7.3	219	33470	9.1	120
33575	7.6	45	33590	7.9	138
33620	7.4	200	33728	9.1	110
33820	7.8	57	33838	8.1	112
33877	7.6	248	33950	9.2	288
34125	7.7	195	34238	8.9	137
34320	8.2	105	34375	8.4	106
34425	8.1	105	34481	8.9	141
34530	8.3	143	34622	8.7	128
34673	8.1	157	34750	8.9	140
34830	8.3	88	34890	8.7	108
34918	8.2	131	34998	8.9	132
35049	8.1	136	35130	9.2	119
35185	7.6	109	35249	9.0	131
35294	8.1	158	35380	9.0	132
35452	7.9	128	35512	8.4	—
35580	8.1	—	—	—	—
—	—	—	35788	8.5	112
35863	8.1	109	35900	8.5	—
35972	8.0	—	—	—	—

International Observations of a Supernova in NGC 2841. The discovery of a possible supernova in the bright, spiral nebula, NGC 2841, was announced by Professor M. Schürer of the Astronomical Institute, Bern, Switzerland. Its position was 2 minutes north-west of the nucleus, and it was about 14th magnitude on March 1. The supernova was confirmed by Dr. E. F. Carpenter of the Steward Observatory, Tucson, Arizona, on photographs taken on March 5 and 8. Dr. Sidney van den Bergh of the Perkins Observatory, Delaware, Ohio, also photographed it on March 5.

A pre-discovery photograph of the supernova, taken on February 25, has just been received from Eugenio C. Silva of Alfeite, Portugal. The nova apparently remained at about the 14th magnitude from February 25 through March 8. By March 20, it had faded about one magnitude, according to observations from the Skalnate Pleso Observatory, Czechoslovakia, and from the observatory at Sonneberg, Germany.

This is the second supernova to have been discovered in NGC 2841. The first one was discovered in February 1912 by F. G. Pease of Mount Wilson Observatory. It reached a maximum of about 16th magnitude.

Observations received during May and June 1957: In May, 51 observers contributed 3,020 observations, and in June, 51 sent 3,788, a total of 6,808 observations for the two months.

Observer	May		June		Observer	May		June	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Adams, R. M.	59	135	60	135	Lacchini, G. B.	27	57	31	65
Anderson, C. E.	87	114	78	105	Lowder, W. M.	2	5	5	5
Aronowitz, C.	66	66	106	202	Maran, S. P.	10	11	35	50
Beidler, H. B.	13	13	8	8	McPherson, C. A.	..	..	10	10
Berg, R.	..	..	8	8	Miller, J. S.	2	2	..	..
Bicknell, R. H.	15	102	20	167	Montague, A. C.	19	30	34	50
Breckinridge, J.	2	7	13	29	Morgan, F. P.	13	17	6	11
Buckstaff, R. N.	..	..	13	18	Oravec, E. G.	183	431	188	389
Carlisle, J. H.	3	8	1	2	Panke, D.	3	3	..	..
Carpenter, C. B.	4	4	10	10	Parker, P. O.	75	116	86	105
Charles, D. F.	7	22	..	..	Pearcy, R. E.	3	3	3	3
Cragg, T. A.	24	24	143	166	Pearlmutter, A. G.	43	95	98	225
*Darsenius, G.	15	46	7	7	Peltier, L. C.	24	112	23	80
Debono, I. P.	..	..	3	3	Pilcher, F.	6	7	9	9
Diedrich, DeL.	1	2	2	4	Price, F.	23	57	29	92
Diedrich, G.	7	13	4	17	Renner, C. J.	124	148	..	..
Erpenstein, O. M.	6	6	2	3	Rizzo, P. V.	16	25	23	29
Fernald, C. F.	169	312	195	282	Robinson, L. J.	25	81	31	48
Ford, C. B.	125	127	160	175	Rosebrugh, D. W.	11	57	10	65
Gemberling, R. H.	6	16	10	25	Royer, R.	9	10	..	..
Gernant, P.	..	..	1	1	Segers, C. L.	15	32	26	61
Goodsell, J. G.	1	1	3	3	Sharpless, A. P.	..	..	16	19
Hartmann, F.	115	125	121	127	Skaritka, P.	40	43	..	..
Hiett, L.	6	11	..	..	Solomon, L.	14	14	59	83
Howarth, M.	21	21	19	19	Thomas, M. A.	6	10	..	..
Hutchings, N.	6	6	4	4	Thurn, V. W.	18	20	10	10
Jacobson, R.	..	..	2	2	Tsai, C. H.	..	..	22	37
Johnsson, R. G.	..	..	4	4	Venter, S. C.	38	48	50	104
Kelly, F. J.	10	10	11	11	Walko, K.	..	..	3	3
deKock, R. P.	121	378	133	695	Wyckoff, J.	15	15	..	..
Kofoed, R.	2	2	..	..					

*Plus YZ CMi $1^h\ 25^m$

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman): Observations of Nova Search Areas were made by the following twelve members for a total of 183 area-nights. Each name is followed by the number of observations for April 1957 and May 1957: James Breckenridge—14, 13; Christine Culp—5, 0; DeLorne Diedrich—3, 8; George Diedrich—10, 20; Richard Gemberling—4, 16; Robert Jacobson—4, 12; Andrew Keefer, Jr.—30, 0; Stephen Maran—0, 4; Earl Milton—9, 0; Beaufort Ragland—0, 7; Jane Shelby—13, 0; James Wesling—4, 7.

A.A.V.S.O. Headquarters,
4 Brattle Street,
Cambridge 38, Mass.,
July 1957.

NOTES FROM OBSERVATORIES

Dominion Astrophysical Observatory, Victoria, B.C.

R. Wilson of the Royal Observatory, Edinburgh, arrived in April to commence a postdoctoral fellowship awarded by the National Research Council.

E. G. Ebbighausen of the University of Oregon was appointed visiting astronomer for the summer months. Other summer appointments included: J. L. Climenhaga of Victoria College, E. Butkov from McGill University, and A. K. Goodacre and S. C. Morris from the University of British Columbia.

Miss J. K. McDonald returned to the Observatory in July, having spent the academic year 1956–57 at the University of California, Berkeley.

During the early part of the summer P.E. Argyle assisted J. L. Locke of the Ottawa Observatory in surveying radio telescope sites.

G. J. Odgers spent two months in California using the 100-inch and 60-inch Mount Wilson telescopes for observations of β Cephei-type stars.

Miss A. B. Underhill has begun, in collaboration with R. Thomas of Harvard Observatory, the problem of calculating the Stark component f-values for hydrogen, making use of the calculating machine facilities at Boulder, Colorado.

Members of the staff attending astronomical meetings included: Miss A. B. Underhill, American Astronomical Society meetings in Cambridge in May; J. A. Pearce, Royal Society of Canada meetings in Ottawa in June; A. McKellar and Miss J. K. McDonald, Astronomical Society of the Pacific meetings in Flagstaff in June.

K. Whitham and E. I. Loomer spent part of July at the Observatory installing an auroral camera and intensity recorder and putting into operation the equipment of the magnetic observatory. These instruments will be operated during the International Geophysical Year by B. Caner, who arrived at the Observatory in July. In addition, ionospheric sound equipment has been installed on the Observatory hill by the Defence Research Board for operation during the International Geophysical Year.

P. Willmore of Ottawa visited the Observatory in July in connection with the development of the Seismological Programme in British Columbia.

Complete new wiring and a new control console have been installed for the operation of telescope and dome.

On July 10 a "live" one half-hour CBUT television programme was broadcast from the dome. Members of the staff taking part were Andrews, Odgers, Petrie, Salonen, Underhill and Wright.

At the request of officials of Victoria College, R. M. Petrie and A. B. Underhill participated in the summer session of the College, presenting a non-credit course of instruction in astronomy.

Visitors to the Observatory included B. J. Bok, Commonwealth Astronomer; B. Westerlund of Stockholm; J. H. Hodgson, Dominion Seismologist; F. K. Edmondson, representing the National Science Foundation; J. Sahade of Berkeley; and W. Steinlin of Switzerland.

J. K. McD.

REVIEW OF PUBLICATIONS

Realities of Space Travel edited by L. J. Carter. Pages 431, 5½ × 8½ inches. London, Putnam and Company Limited, 1957. Price £1.15.0.

Realities of Space Travel is a group of selected papers of the British Interplanetary Society covering the whole field of space travel. Sections are included dealing with astronautics; the satellite vehicle; interplanetary flight; physical and biological factors in space flight; establishments and testing stations; targets for tomorrow; and interstellar flight.

These papers have a factual basis and do serve to give a reasonably clear concept of reality, although in some cases the arguments necessarily are not conclusive. In general, the book includes sufficient mathematics to prove many relevant points, yet keeps the discussion simple enough to maintain the interest of the average amateur reader.

William R. Hossack

Astronomical Optics and Related Subjects (Proceedings of a symposium held at the University of Manchester, 1955) edited by Zdenek Kopal. Pages xv plus 428; 6 × 9 inches. Amsterdam, North Holland Publishing Company, and New York, Interscience Publishers, Inc. Price $12.50 U.S.

This book is not a treatise on telescopes and spectrographs, although in the introductory chapter Dr. Kopal has written an interesting summary

of astronomical optics to the present time. Instead, the reader stands in the company of experts at the threshold of new developments.

Over 100 scientists met in Manchester in April 1955 to discuss astronomical optics and observational methods in the widest sense of the word, and this is the record of that symposium. Its purpose was to provide a forum for discussion of certain fields in optics of timely interest and astronomical significance, and to strengthen the liaison between astronomy and optics.

The seven section headings reveal the scope of the book; they follow the organization of the symposium by topics: Information theory and optics; Optical images and diffraction; Interferometry and coherence problems; Electronic devices in astronomical optics; Resolution problems and scintillation; Wide-angle optical systems and aspheric surfaces; and Filter photography and thin films.

The majority of the 46 articles by some 50 authors (mostly European) are in English, ten are in French, and two in German. Some of the papers presented at the symposium regrettably do not appear in the book for various reasons, and some which do have necessarily been abridged. The editor apologizes for the lack of a subject index on account of the multi-lingual character of the contents, but a Name (not Author) Index has been provided. There are numerous half-tone illustrations and diagrams. The book is attractively printed and bound.

Because of the wide range of subject matter within the domain of optics, there are surely many articles in this book which will be of interest to every astronomical reader, amateur or professional. Even a cursory leaf-through will bring home the realization that optics, far from being a stagnant technique, is a wide-ranging and rapidly developing branch of science. It seems certain that new advances in astronomy will come through the channels, now being opened up, which are described here.

D. A. M. R.

The Airglow and the Aurorae edited by E. B. Armstrong and A. Dalgarno. Pages ix plus 420, 7½ × 10 in. London and New York, Permagon Press. Price $22.50.

This book is a collection of fifty-three communications concerned with all phases of auroral and airglow research which were made to a symposium held at Belfast, Northern Ireland in September 1955.

The book opens with an introduction by Sydney Chapman which gives an historical review of research in this field and delineates some prominent gaps which future research must endeavour to fill. This is followed

by four sections on observations and theoretical considerations concerning aurorae and the airglow. Three final sections discuss laboratory studies, quantal calculations and instrumentation.

The communications in this book are of the nature of papers such as are normally disseminated through scientific journals and will be of interest primarily to an audience conversant with earlier work in the fields covered. This book is not a review of the present state of knowledge about the airglow and aurorae but as the editors write, "The papers presented constituted a coherent survey of the most recent work on observational, experimental and theoretical aspects of the phenomena, and it was considered very desirable, especially in view of the imminence of the International Geophysical Year, that they should be published in a single volume."

The book is very well printed and bound; its price is extremely high. Whether the dissemination of scientific contributions in such expensive formats is the most effective means of spreading knowledge and advancing science appears very doubtful to this reviewer.

L. T. S.

NOTES AND QUERIES

Solar Activity and Comets

In a recent issue of the *Russian Astronomical Circular* (no. 178, p. 3, March 12, 1957) Bakharev reports on his observations of the brightness of Comet 1955f and of a possible relation to the sun's activity. He noticed a sudden increase of the integral brightness of the comet by 0.8 mag. during the period 1955 August 8–12 at the time of increased solar activity. Plotting the observed magnitude of the comet and simultaneously the relative Wolf numbers against the time he obtained two curves which show great similarity. According to observations three large spot groups crossed the central meridian of the sun about August 10–11. One of the groups was visible to the naked eye.

A possible similar case is reported in the Announcement Card 1364 of the Harvard College Observatory. According to this Comet Wirtanen (1956c) has been found at the predicted position but much brighter than expected. It may be appropriate to quote the final sentence of the Announcement Card: "The unexpected increase in brightness suggests the value of physical observations".

G. A. B.

The Moon and Earth in the I.G.Y.

During the International Geophysical Year photographs of the moon, taken with special cameras located at some 20 stations around the earth, will give the size and shape of the earth by a method based solely on geometry and independent of the pull of gravity. The photographs will yield the relative positions of the continents to within a few feet, an accuracy far superior to previous determinations. In fact by comparing the observations obtained at this time with those taken in the future, the amounts and directions of shift of the continents can be determined. These measurements are considered of "epochal importance". (*Science News Letter*, June 22, 1957.)

The camera which makes this advance possible is a new type developed by Dr. William Markowitz at the U.S. Naval Observatory, and can simultaneously photograph the moon and the background stars. Normally, because the moon is so bright, a very short exposure is required to photograph it clearly, and this short exposure is not nearly

enough to "bring up" the stars. The "dual-rate moon-position" camera, as it is called, has a dark, tilting filter which cuts out all but about one-thousandth of the moon's light; the movable filter allows both the moon and the stars to be photographed at the same time. A series of photographs taken on a single night with this camera will give the accurate position of the observing station with relation to the centre of the earth and the stars.

Extensive observations with the "moon-position" camera will give results of another kind: they will allow a check on Ephemeris Time, which is measured from the orbital motion of the moon or other celestial body. Universal Time, given by the rotation of the earth, has been found to vary because of changes in the rate of the earth's rotation. Part of the variation is regular and is roughly explicable and part is irregular and unpredictable. By obtaining the uniform Ephemeris Time with great accuracy from the special photographs of the moon, it is hoped that the irregular changes in the earth's rotation may be able to be correlated with other geophysical events.

R. J. N.

NGC 4676—A Colliding Galaxy

During an inspection of the Palomar Sky Survey Atlas Vorontsov-Veliaminov (see *Russian Astronomical Circular*, no. 178, p. 19, March 12, 1957) noticed that the galaxy NGC 4676 consists of two elliptical nuclei connected by a bright bridge. The most remarkable features of these objects are two spiral arms connected with the first galaxy and a very bright tail—similar to the tails of comets—pointing straight away from the nucleus. In the opinion of the author this tail cannot be a projection of a third spiral arm. Also he has reasons to believe that it is formed by stars and not by relativistic electrons. He therefore concludes that NGC 4676 consists of two colliding galaxies. No radiation at radio frequencies has been detected.

It is generally accepted that colliding galaxies are sources of radio radiation. This is true for the galaxy in Cygnus, NGC 4038, but in all the other (few dozen) instances examined by Vorontsov-Veliaminov no radio sources were found. Therefore he suggests the view of Ambartsumian, that radio galaxies are objects splitting into two parts and may be strong sources of radio radiation, whereas colliding galaxies in general do not emit radiation at radio frequencies.

G. A. B.

MEETINGS OF THE SOCIETY

AT MONTREAL

October 18, 1956—The 38th Annual Meeting of the Montreal Centre was held at Macdonald Physics Building, McGill University, at 8:15 p.m. The President, Mr. Chas. M. Good occupied the chair.

The election of Officers and Council members for 1956–57 took place, followed by reports from the retiring Secretary, Treasurer, Librarian, and Director of Observations.

The lecture of the evening was given by Mr. E. Russel Paterson, his title being "The Variations in the Sun's Reputation". The speaker traced from ancient times the varying degrees of importance with which the sun has been regarded. When the earth was considered the most important body in the universe, the sun was in relatively low esteem, but with Copernicus and Kepler it rose to supreme importance. This importance declined when the sun was discovered to be just another star, and not even an outstanding one. More recently, surveys of stars within 16 light-years have indicated that the sun is a "better than average" star, and its reputation is again on the ascendant.

The Annual Meeting was closed with a social hour. Ninety members and visitors were present.

November 8, 1956—The meeting was held at Macdonald Physics Building, McGill University. Following the ordinary business formalities, a lecture was given by Dr. Gerald S. Hawkins, Harvard College Observatory, entitled, "Radar Astronomy".

Innumerable stars may be seen in the sky, yet in the dark spaces between them are invisible "stars" which emit signals, for the reception of which radio telescopes are used. These instruments collect radio waves, and channel them into radio receivers. The signals received are in the form of noise, and are graphically recorded together with time and intensity. The so-called *radio stars* are centres from which radiation comes, such as the source in Cygnus, which seems to be two galaxies in collision, near the limit of the visible universe. Another source is in Cassiopeia and has not been identified with any known optical source. A source in Taurus has been identified as the Crab Nebula, the remnants of a star disrupted by atomic explosion.

The spiral structure of the galaxy is being mapped by studying the velocity and position of the radiation received at a frequency of 1,420 megacycles or a wave-length of 21 cm. This is the wave-length of neutral hydrogen.

The planets also send out radio noise. From the planet Jupiter the source seems to be the Great Red Spot. From the signals from Mars an estimate of 77° F. has been made of the surface temperature at the centre of the disc. Similarly, the surface of Venus has been found to be about the temperature of boiling water.

Radar techniques are also used, by sending out signals which are reflected back from astronomical objects like the meteors and the moon. Time lag provides a way of calculating distances. It was pointed out that construction of instruments of the enormous size required, imposes limiting factors in this field of research.

E. E. BRIDGEN, *Secretary.*

AT TORONTO

November 27, 1956—The meeting was held in the McLennan Physics Laboratory, University of Toronto, Mr. G. A. Cooper presiding.

Dr. J. F. Heard spoke in tribute of Dr. C. A. Chant who had recently died. Dr. Helen Hogg spoke of the passing of Mr. C. F. Publow.

Mr. L. H. Clark, Chairman of The Nomination Committee, presented the slate of officers recommended for 1957.

Dr. J. B. Oke introduced the speaker, Dr. Merle Walker of The Warner and Swasey Observatory. This was an illustrated lecture entitled "The Mystery Of Nova Herculis". Dr. Walker described the studies made of this star since it exploded in December 1934. Nova Herculis is of great interest because it has been found to be an eclipsing variable with a depth of primary eclipse of 1.3 magnitudes in yellow light, the interval between successive eclipses being 4 hours 39 minutes, the eclipse lasting about one hour. Since the depth of eclipse is greater than three-quarters of a magnitude the secondary eclipse is unobserved and the period is 4 hours 39 minutes. This indicates that the secondary component, which is in front during principal eclipse has a much lower surface brightness than that of the primary star.

DQ Herculis is important because it is a binary and therefore we can determine physical nature of the system. The darker star is larger than the brighter being thirty-seven one-hundredths of the orbital radius, the brighter star is thirty one-hundredths of orbital radius. There is uncertainty about the masses. Assymetry of the light curve and a dip at maximum indicate a mass of gas within the system. The question is asked, are all novae binaries? Also, was the star double before its outburst; what was its early history? There is much yet to be learned about DQ Herculis and similar objects before such questions can be answered.

Mr. R. R. Broadfoot thanked the speaker.

December 11, 1956—The meeting was held in the McLennan Physics Laboratory, University of Toronto, Mr. G. A. Cooper presiding. This was the Annual Meeting of The Toronto Centre.

The following reports were presented and adopted: Secretary's Report; Treasurer's Report; Report of Nominating Committee.

Following the business meeting Dr. G. D. Scott gave a lecture on low temperatures. The talk was profusely illustrated with numerous and spectacular demonstrations showing the behaviour of substances cooled by liquid air. In addition to the highly entertaining experiments, Dr. Scott presented a generous helping of facts and figures about low temperature.

Mr. D. Gerrie thanked the speaker.

R. R. Broadfoot, *Recorder.*

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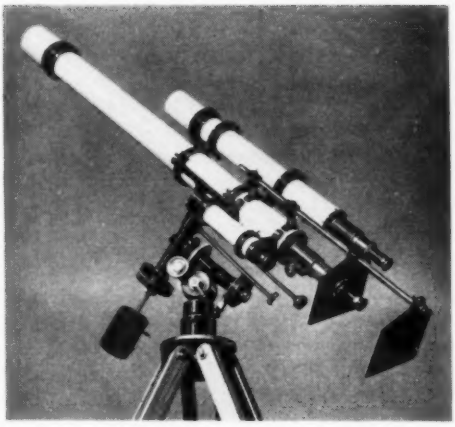

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